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Terrestrial pollen record of recent land-use changes around nine North African lakes in the CASSARINA Project

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Abstract

Pollen analyses and related plant macrofossil records are presented from short cores from nine North African lakes in the EU-funded CASSARINA project. Terrestrial pollen reflects human impact on the vegetation and landscape over the last 150–100 years. Pollen changes, aided by radiometric dating, could be correlated with historical developments. The chronology of the landscape changes date other biostratigraphical records reflecting changes in the aquatic ecosystems.

Three lakes in Morocco show gradually intensifying land-use over the last century. Accelerated technological development and landscape modification over the last 20 years culminated in one of the lakes being drained and cultivated during the project period. In Tunisia, a nationally unique acid-water lake is threatened by water withdrawal for increased catchment cultivation. The landscape around two other lakes is being increasingly cultivated and urbanised, and water withdrawal to support this has resulted in deleterious effects on the aquatic ecosystems, particularly at the internationally famous Garaet El Ichkeul where reed-marshes and macrophyte beds have been lost. The three lakes in the Egyptian Nile Delta are in the same hydrological system and show parallel changes in the balance between saltmarsh and reed-marsh. Control of Nile floods and year-round irrigation led to marked increases in cultivation in the delta region since ca. 1920. The Aswan High Dam (1964) had little detectable further effect. Documented planting of dates, palms, and olives and of introduced *Casuarina* and *Eucalyptus* trees provided a chronology to supplement the unsatisfactory radiometric dating of the sediments in this low-rainfall area.

Introduction

Over the past 100–150 years, coastal areas of North Africa have experienced great increases in human impact on the environment. An EU-funded project CASSARINA: 'Change, stress and sustainability: aquatic ecosystem resilience in North Africa' was initiated in 1997 (Flower, 2001). As part of this project pollen analyses of short sediment cores from nine lakes in Morocco, Tunisia, and Egypt have been made to reconstruct changes in vegetation around these sites in response to increasing human impact. North African lakes are very often important resources for both humans and their animals, and for other biota, including birds. It is vital that their present status and the effects of recent human impacts be assessed so that, if possible, their biodiversity can be maintained in the future (e.g., Kassas, 1971; Morgan & Boy, 1982; Mitchell et al., 1985).

The terrestrial pollen record provides evidence of changes in the vegetation and land-use around each site and also reflects regional influences by linking the changes found to historical records. Furthermore, some of these changes (reed-bed loss, local de- or afforestation, cereal crop production, and soil erosion) are very likely to effect the aquatic ecology and hydrology of nearby lakes. Within the project the pollen record was used (i) to reconstruct past changes that have occurred in the vegetation surrounding each lake, (ii) to help interpret past changes that occurred in the aquatic ecosystem at each lake, (iii) to supplement or validate the radiometric dating and the derived timescale for these sediment sequences.

A few palaeoecological studies have previously been made in North Africa, but are usually not at a sufficiently high time resolution to provide evidence of changes over the last 100–150 years. However, in Morocco multiproxy palaeolimnological studies covering ca. the last 100 years have been made from Dayat-er-Roumi, a lake on the alluvial coastal plain to the east of Rabat with an extensive agricultural catchment (Flower et al., 1989), and in Tunisia on Garaet El Ichkeul, one of the lakes studied in this project (Stevenson& Battarbee, 1991; Stevenson et al., 1993). Holocene palaeoecological studies from the coastal region of Egypt have been made by Leroy (1992), Mehringer et al. (1979) have investigated the vegetational history of the Fayum depression southwest of Cairo, and Reille (1979) presented a Holocene pollen diagram from Sidi Bou Rhaba (Morocco).

The sites

Nine sites were selected, three from each of Morocco, Tunisia, and Egypt, to represent the range of lakes occurring in coastal North Africa (Flower, 2001). They all occur at similar latitudes (31–37º N) but are spread over 25º longitude (6–31º E), i.e., over a span of ca. 3000 km. They have all been subjected to human impacts that include hydrological changes (damming, canalisation, withdrawal of water for agriculture), input of sewage and industrial waste, input of fertilizers and pesticides, and reclamation by drainage and land- fill (Ramdani et al., 2001a). Further details of the sites are given in Ramdani et al. (2001a).

Methods

Besides pollen analyses, macrofossil, diatom, zooplankton, and geochemical analyses have been made on the sediment cores (Birks et al., 2001; Flower, 2001; Flower et al., 2001; Ramdani et al., 2001b) and the sediments have been dated as far as possible radiometrically (Appleby et al., 2001).

Coring

In 1997 and 1998, two short cores were obtained close to each other from each lake, usually from the centre, using a modified Livingstone corer except for Merja Bokka (Morocco) where a standard Livingstone (1955) corer was used as the sediments were very consolidated (see Flower, 2001). A central core (BURL1) and a marginal core (BURL2) were taken from Burullus Lake (Egypt).

The master core was used for lithostratigraphical, diatom, radiometric, zooplankton, and pesticide analyses. The second core was sectioned at 2 cm intervals for pollen, macrofossil, lithological, and heavy metal analyses. The samples were kept at 4ºC until required.

Chronology

Radiometric chronologies were constructed, where possible, for the master core from each site (Appleby et al., 2001). Both cores from Burullus Lake (see above) were measured for radionuclides, but BURL1 had little useful record. Otherwise each pair of sediment cores has similar lithostratigraphies (Birks et al., 2000; Flower et al., 2001) and dating was transferred from the master cores to the second cores used for the pollen and macrofossil analyses.

Pollen and macrofossil analyses

Eight or ten samples were prepared for pollen analysis from each site using method B of Berglund and Ralska-Jasiewiczowa (1986). The residues were suspended in 2000 cs silicone oil. Tablets of a known concentration of *Lycopodium* spores were added to each sample prior to preparation so that fossil pollen concentrations could be estimated. Identification and counting were at a magnification of 400x with critical determinations at 1000x. Identification was aided by a modern pollen reference collection including material collected from the Sudan by El Ghazali (1989), and illustrations including Reille (1992, 1995) and Ayyad and Moore (1995). A minimum of 300 determinable grains excluding obligate aquatics was counted from each sample. Selected pollen taxa, expressed as percentages of the total determinable terrestrial and marsh pollen and spores, and total pollen and spore concentrations, are shown on Figures 1–9. Unshaded silhouettes are exaggerated x10 scale. Pollen curves of aquatic taxa are not presented as they are published by Birks et al. (2001). The complete microfossil data from the sites will be lodged with the African Pollen Database (APDB). The pollen diagrams were calculated and drawn using the programs TILIA and TILIA.GRAPH (Grimm, 1990). Each pollen sequence has been divided visually into local pollen zones for the purposes of discussion.

Detrended correspondence analysis (DCA) (Hill & Gauch, 1980) was applied to the pollen-stratigraphical data from the nine sites independently so as to estimate the total variability ('inertia') and the amount of compositional change or 'turnover' in standard deviation (SD) units within each stratigraphical sequence (Table 1). Prior to DCA the percentage data were transformed to square roots in an attempt to stabilise variances. In the DCA detrending was by segments, non-linear rescaling was implemented, and rare taxa were downweighted. All computations were done with CANOCO 3.12a with strict convergence criteria. Low variance and turnover suggest little pollen stratigraphical change in the sequence in question, whereas high variance and/or turnover imply more palynological change.

Table 1. Total variance and compositional change (= gradient length of axis 1) in the pollen stratigraphical data from the nine sites, as estimated by detrended correspondence analysis

	Total variance ('inertia')	Compositional change (SD units)
Morocco		
Merja Sidi Bou Rhaba	0.42	1.05
Merja Zerga	0.43	0.90
Merja Bokka	0.47	1.13
Tunisia		
Megene Chitane	0.39	0.89
Garaet El Ichkeul	0.46	0.84
Lac de Korba	0.43	1.11
Egypt		
Edku Lake	0.62	1.26
Burullus Lake	0.63	1.27
Manzala Lake	0.62	1.29

SD = standard deviation or turnover units. See Hill and Gauch (1980).

Macrofossil remains were sieved out of a known volume of sediment (usually ca. 25 cm3). The method and results are described by Birks et al. (2001). The occurrence and relative abundance of relevant macrofossil taxa is indicated by dots in Figures 1–9. Macrofossil taxa are fruits or seeds unless otherwise specified.

Plant nomenclature follows the incomplete floras by Fennane et al. (1999) and Boulos (1999) where possible. Other nomenclature follows Tutin et al. (1964–1980).

Results and discussion

There are several problems in pollen analysis which are particularly pertinent to the data from the nine North African lakes. Firstly, what is the pollen source area? This varies greatly between the sites. Some, such as Merja Sidi Bou Rhaba and Megene Chitane, are small enclosed lakes in a vegetated landscape without permanent inflows or outflows, and therefore probably have a high local component in their pollen assemblages. In contrast, the three Egyptian Nile Delta lakes are extremely large (ca. 1000 km2) and very open, and receive water from the sea and the Nile. Such lakes may include a large long-distance water-borne and aerial component in their pollen assemblages. A second problem is that of 'silent' taxa. These taxa produce very little, usually entomophilous, pollen but may be common in the vegetation around the site. A particular example in Mediterranean regions is the Leguminosae whose members are found extensively in the vegetation but are very poorly represented in the pollen assemblages. Many 'crops' are also rarely recorded including cereals, palms, and members of the Solanaceae, potatoes, tomatoes, peppers, etc. Other pollen types may be fragile and poorly preserved, so that they are rarely found. *Juncus* pollen is an example, but *Juncus* seeds are often found, thus illustrating the importance of parallel macrofossil studies to gain a more complete picture of the vegetation. Thirdly, pollen preservation may be a big problem in some of these lakes. Where water is shallow, lakes may dry up in part, allowing pollen to be oxidised and deteriorated so that identification becomes impossible. However, despite these problems it has been possible to use the terrestrial pollen and terrestrial macrofossil records to reconstruct recent land-use changes around the sites.

Merja Sidi Bou Rhaba (Morocco) 34º12'N, 6º42'E

This small lake lies in a valley formed by sand dunes, and is surrounded by woodland and scrub (Ramdani et al., 2001a). Its catchment is small and most of the pollen is probably locally derived. It is a valuable wildlife (RAMSAR) habitat especially for birds. Sediment accumulation rates have gradually increased (Appleby et al., 2001), but there is little soil erosion from the catchment as there is little agricultural activity (Flower et al., 1992; Ramdani et al., 2001a). The site is threatened by increased siltation and affected by atmospheric pollution (Flower et al., 1992).

The pollen stratigraphy (Figure 1) shows a major change starting in the early nineteenth century at the zone 1/2 boundary with a shift from Gramineae and *Phragmites*-type pollen dominance to an abundance of Cupressaceae pollen (probably *Juniperus phoenicea* which is common around the lake today) and increases in *Typha domingensis*-type (probably *T. angustifolia*) and *Scirpus maritimus*-type pollen (probably *S. lacustris*), and macrofossils of *Juncus*. This suggests that the *Phragmites*-dominated reedmarsh changed to one containing *Juncus*, *Scirpus*, and *Typha.* The large increase in Cupressaceae pollen may be due to a change from grassland to dry *Juniperus phoenicea* scrub, possibly as a response to decreased grazing pressure. The site is today surrounded by relatively undisturbed woodland and scrub containing *Quercus suber, Pistacia lentiscus, Retama monosperma* (a legume whose pollen is rarely found), *Juniperus phoenicea*, *Populus alba*, *Phillyrea angustifolia*, *Chamaerops humilis*, *Tamarix gallica*, and *Olea europaea. Eucalyptus* and *Populus* pollen first appeared in the early 1940s (the beginning of zone 3) which is consistent with the start of planting of *Eucalyptus* and *Populus* in the 1920s (Ramdani et al., 2001a) including a large *Eucalyptus* plantation at the northern end of the lake. Otherwise, Figure 1 suggests that, apart from the *Juniperus* component, the woodland and scrub vegetation has changed little during recent times. Since the site was designated a Nature Reserve in 1975, grazing and rush cutting have been controlled to some extent. However, there is little evidence of this from the pollen record. A slight increase in Chenopodiaceae/Amaranthaceae pollen at the very top together with macrofossils of *Salicornia* *europaea* may suggest an increase in exposed mud since ca. 1982. This is consistent with the severe drought of the 1980s (Ramdani et al., 2001a). There has been moderate vegetational change (Table 1) around the site in the last 100–150 years with the appearance of *Eucalyptus* and other planted genera and the spread of Cupressaceae (? *Juniperus*).

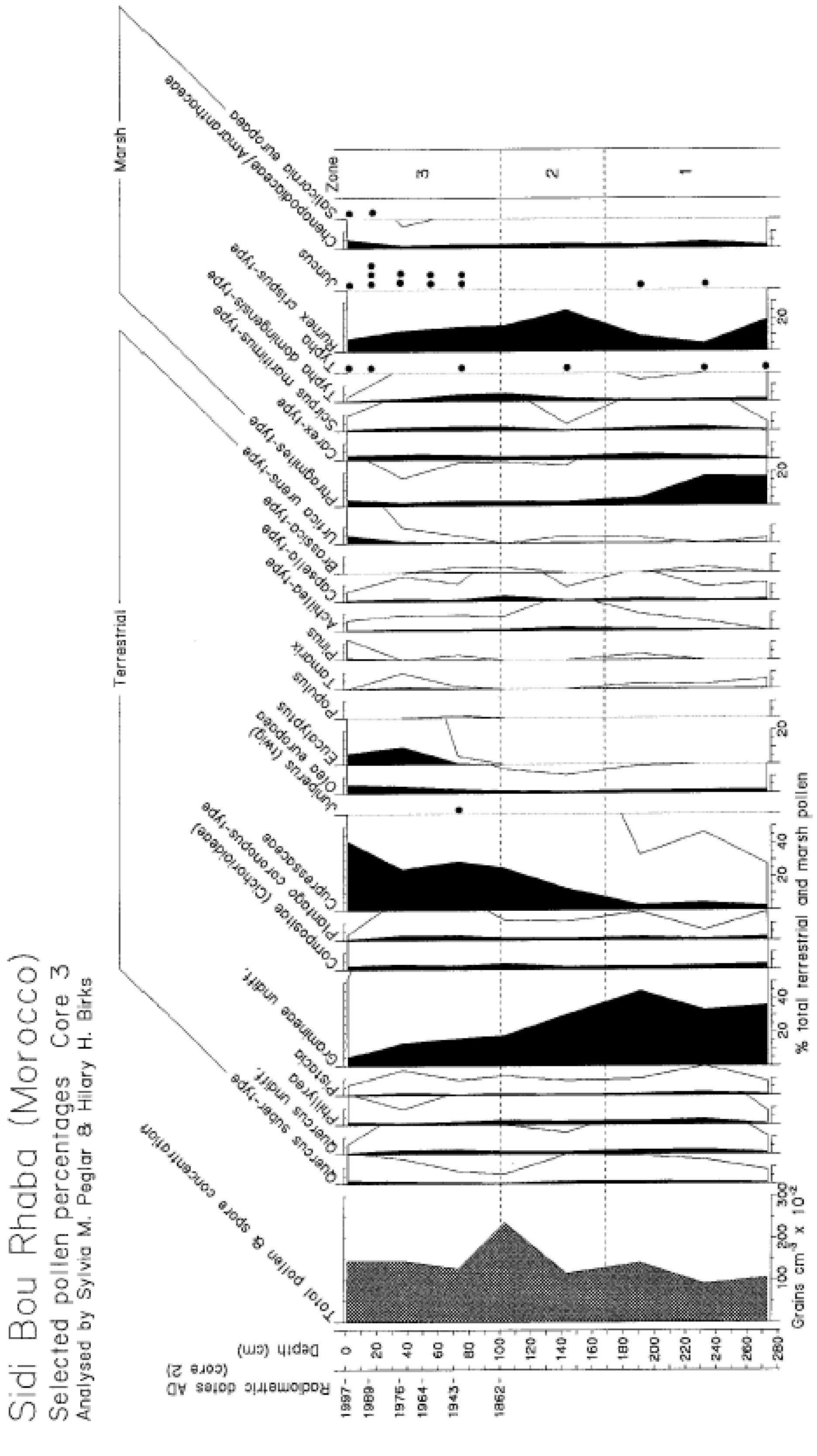

Figure 1. Percentage pollen diagram of selected terrestrial and marsh taxa in core 3 from Sidi Bou Rhaba, Morocco. Total pollen concentrations are also shown, and plant macrofossil records from the same core are indicated by dots. Radiometric ages are transferred from measurements on core 2 (Appleby et al., 2001).

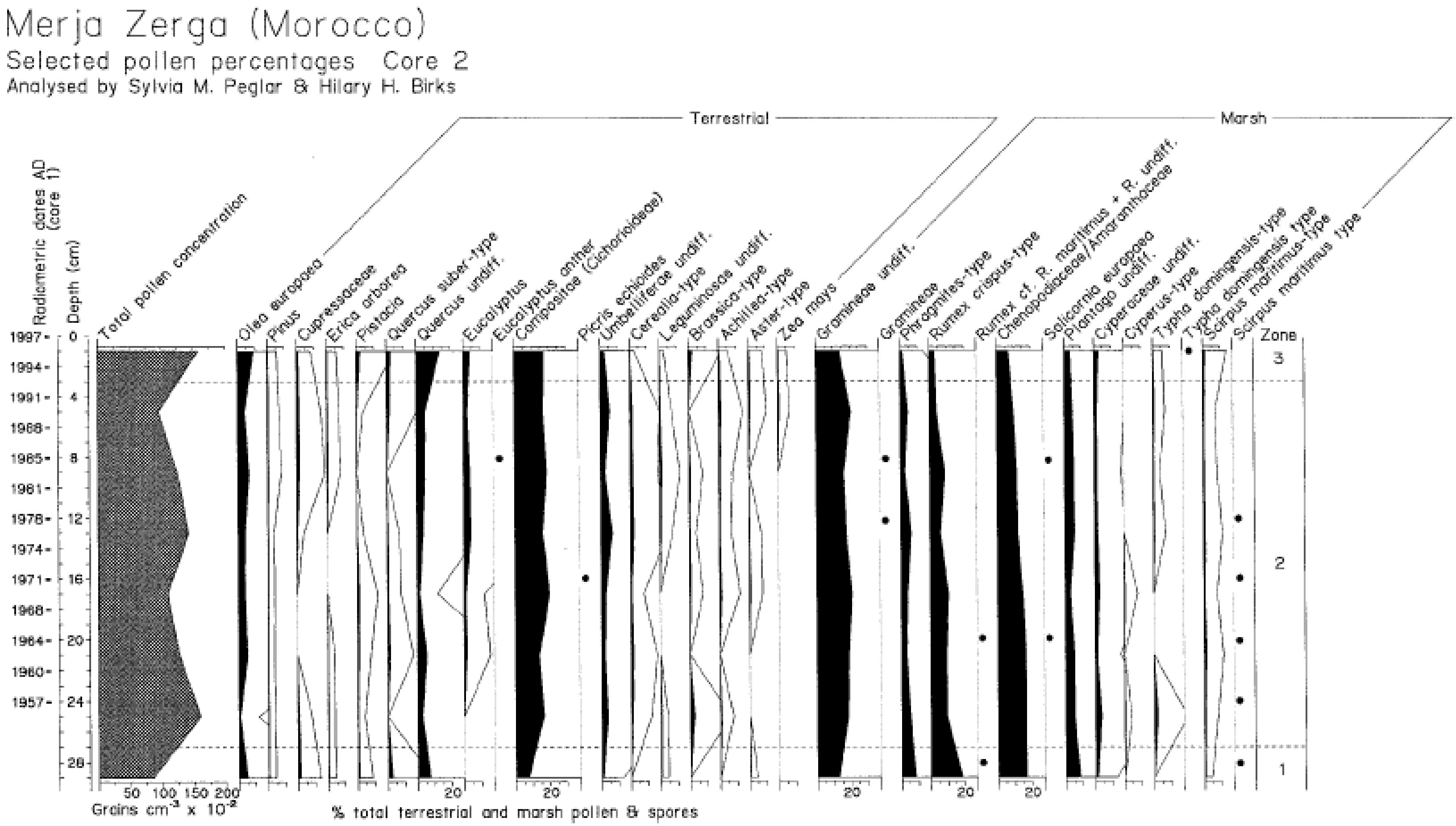

Figure 2. Percentage pollen diagram of selected terrestrial and marsh taxa in core 2 from Merja Zerga, Morocco. Total pollen concentrations are also shown, and plant macrofossil records from the same core are indicated by dots. Radiometric ages are transferred from measurements on core 1 (Appleby et al., 2001).

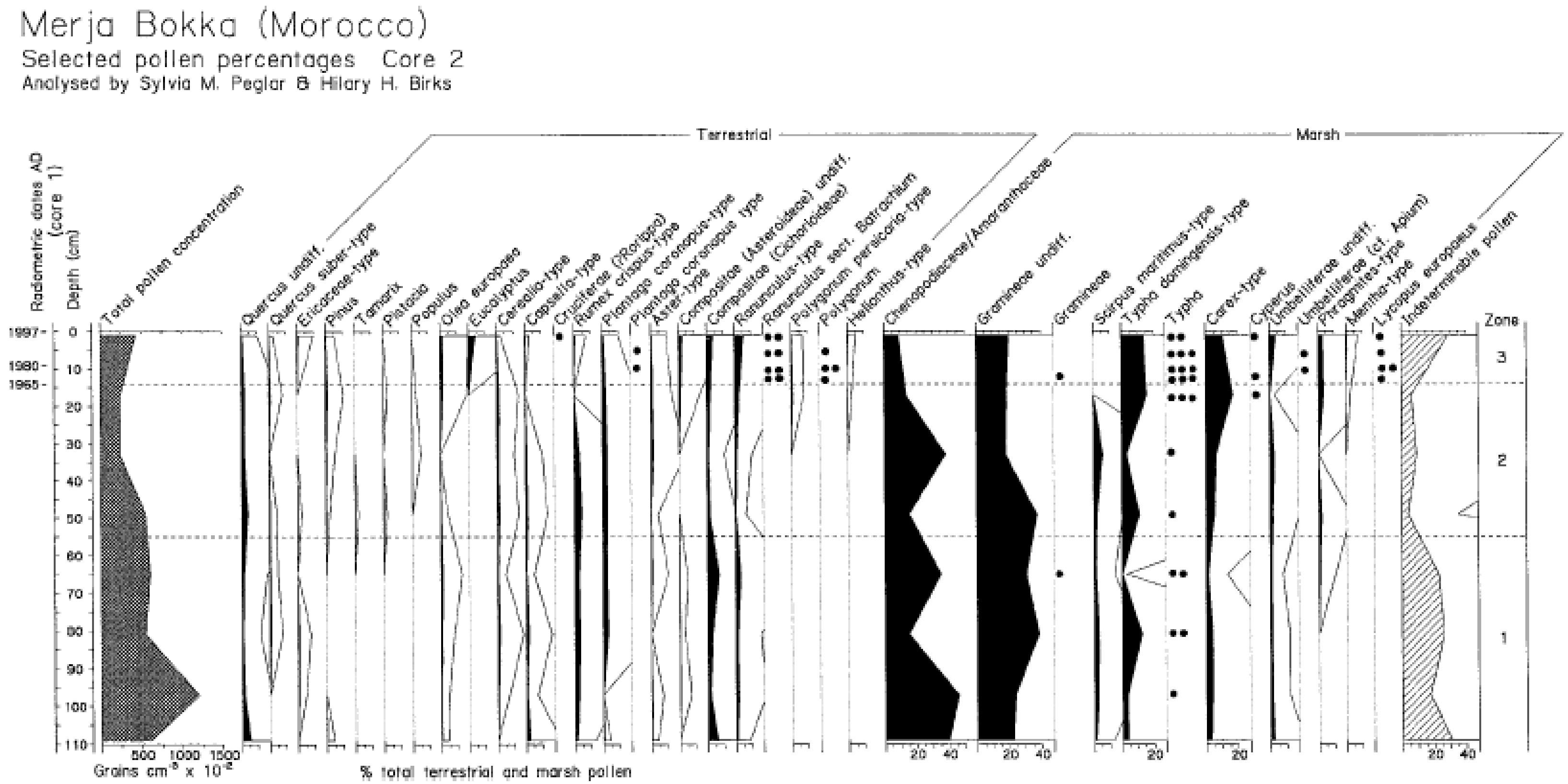

Figure 3. Percentage pollen diagram of selected terrestrial and marsh taxa in core 2 from Merja Bokka, Morocco. Total pollen concentrations are also shown, and plant macrofossil records from the same core are indicated by dots. Radiometric ages are transferred from measurements on core 1 (Appleby et al., 2001).

Merja Zerga (Morocco) 34º17' N, 6º13' E

The Merja Zerga lagoon is tidal but freshwater enters from the Drader river in the northeast and the Nador canal in the south, and it thus has a large catchment (Ramdani et al., 2001a). The lagoon is separated from the sea by unconsolidated dunes and there are low hills to the north, east, and south. There are several settlements around the lake and fishing is very important (Ramdani et al., 2001a). It has been a RAMSAR site since 1971 and a Nature Reserve since 1978.

The pollen record (Figure 2) represents the last 50–60 years (Appleby et al., 2001). The basal sample probably dates to the late 1940s. It contains high percentages of Chenopodiaceae/ Amaranthaceae pollen (probably originating from *Sarcocornia fruticosa* (= *Salicornia arabica*) which was common around the lake before 1950 but is now only abundant on the northern shore, *Suaeda fruticosa*, and *Atriplex tataricus*) together with *Rumex crispus*-type, *Plantago*, and Gramineae (including *Phragmites australis*). After ca. 1950 these taxa gradually decreased and the assemblage became dominated by Compositae (Cichorioideae) and Gramineae, possibly originating from *Hordeum marinum* and *Aeluropus littoralis* that occur around the lagoon today. Cerealia-type pollen reflects widespread cereal cultivation, and *Zea mays* was more widely grown after ca. 1985. Other crops are not represented, and many are grown under greenhouses or canvas covers (Ramdani et al., 2001a). However, many herb taxa represent agricultural weeds and plants of disturbed ground as well as saltmarsh vegetation (e.g., *Rumex crispus*-type, various Compositae, and *Plantago*). Some of this pollen may have been brought to the core-site by the Nador Canal from the southern Rharb area. After 1953 (zone 2) *Juncus* including *J. maritimus* (seeds: Birks et al., 2001) and *Phragmites*-type expanded, but towards the top of Figure 2 (zone 3) *Phragmites*-type decreased and there was a small increase in *Scirpus maritimus*type (*S. maritimus*?) although seed representation had ceased (Birks et al., 2001). Ramdani et al. (2001a) report that the fringing *Phragmites* has been much reduced in recent years by over-grazing and harvesting. *Eucalyptus* pollen is recorded from the late 1950s onwards and there are plantations around the lake today.

The pollen diagram shows moderate percentages of trees and shrubs that probably originated from regional woodland patches, mainly *Quercus suber* forest, and olive groves and scrub growing on consolidated dunes and the foothills of the Rif mountains to the north. Mikesell (1960) reports woodland patches in the 1950s within a few kilometres of Merga Zerga. *Quercus* (including *Quercus suber*-type) and *Olea europaea* percentages increase towards the top of the diagram, suggesting widespread planting or an increased regional pollen representation. The pollen diagram indicates relatively little change in the vegetation around Merja Zerga over the last 50–60 years (Table 1). However, local changes may have been masked by the influence of the large catchment area, and by the fact that many recent agricultural developments are poorly reflected in the regional pollen rain.

Merja Bokka (Morocco) 34º25' N, 6º12' E

Merja Bokka was a freshwater lake in the floodplain of the Sebou river. The floodplain was previously largely covered by reedmarsh that has been increasingly claimed for agriculture (Ramdani et al., 2001a).

The pollen preservation is poor, with up to 30% indeterminable pollen, probably resulting from periods of low water-level with sediment exposure, soil erosion, and oxidation. The base of the pollen diagram (zone 1, Figure 3) is dominated by Gramineae pollen (probably *Phragmites australis*, although the poor preservation makes identification impossible) with some *Scirpus maritimus*-type, *Carex*-type, and *Typha domingensis*-type reflecting the surrounding reedmarsh. The high percentages of Chenopodiaceae/ Amaranthaceae pollen probably originated from plants of these taxa colonising summer-exposed mud. Historical records document an extensive wetland area pre-1930s with exploitation of the rushes for mat-making (Ramdani et al., 2001a). During zone 2 there was a decrease in Gramineae (*Phragmites*?) and an increase in many herbs which may be associated with grazing and agriculture, such as various Compositae, Cruciferae, Leguminosae, *Ranunculus*-type, *Rumex crispus*-type, and Umbelliferae, together with Cerealia-type pollen. Historical records document increased drainage and agriculture around the lake in the 1930s after French colonisation, and these levels probably date from that time. Decreased pollen concentrations above 40 cm suggest a higher sedimentation rate caused by agricultural erosion from the catchment. *Eucalyptus* pollen was found at the top of the diagram. *Eucalyptus* was planted in the 1930s, and then more extensively in the 1960s. A decrease in Chenopodiaceae/Amaranthaceae pollen and increases in *Carex*-type, Cyperaceae undiff., and *Typha domingensis*- type towards the top of the diagram (zone 3) perhaps suggest a decreased water body resulting from the withdrawal of water for agricultural use from the ephemeral inflowing Tiflet river, and the extension of marsh towards the coring site. This can be correlated with flood control of the Sebou river and the conversion of swampy land into agricultural fields during the twentieth century (Ramdani et al., 2001a). Although marsh pollen taxa have increased percentages, they may be giving a false picture, as the local marsh flora was displaced by commercial crops such as peanuts, citrus fruits, tomatoes, potatoes, melons, peppers, and sunflowers, all of which produce little pollen. In 1999 the lake basin was ploughed and planted with sunflowers (*Helianthus*-type pollen occurs near the top of zone 3). As a result of intense human activity the lake and its surrounding wetlands are now lost.

Megene Chitane (Tunisia) 37º11'N, 9º10'E

Megene Chitane is a small lake at 150 m altitude on the northern slopes of the Jebel Chitane. It is fed by rainwater and springs from a sandstone aquifer that trickle down through a peat bog. The water is therefore slightly acidic. The small outflow is now usually above the water level. A wave-cut beach 1 m above the present lake level shows that it was formerly larger (Ramdani et al., 2001a). The catchment contains oak and pine woodland with a shrub understory and typical Mediterranean garrigue (Ramdani *et al.*, 2001a).

The pollen sequence (Figure 4) probably represents the last 100 years (Appleby et al., 2001). At the base high Gramineae (*Phragmites*?) and *Typha domingensis*- type pollen percentages suggest that there was quite an extensive marsh around the lake. Cultivation in the catchment is indicated by high values of crop pollen (Cerealia-type and *Zea mays*) and pollen of weeds such as *Artemisia*, several Compositae, Cruciferae, *Rumex crispus*-type, and Umbelliferae. However, 25% tree and shrub pollen, mostly *Quercus*, but with a range of shrubs (Figure 4) indicate the presence of oak woodland with a scrub understory in the catchment. Before 1950 tree and shrub pollen increased. The concomitant decrease in pollen percentages of herbs associated with cultivation suggests that some of the cultivated land was abandoned, probably during World War 2, allowing woodland and scrub to regenerate, also reflected in the large increase in *Erica arborea* macrofossils (Birks et al., 2001). The pollen percentages of marsh taxa also decreased, suggesting reedmarsh decline. Birks et al. (2001) suggest the lake may have become blanketed by *Juncus bulbosus.* The macrofossil record shows that emergent *Juncus* species became common in the 1960s (Birks et al., 2001). Over the last 20 years rises in *Zea mays*, Cerealia-type, and weed pollen are evidence of renewed cultivation. This agrees with historical records of crops being grown on and near the peat bog since 1980.

The pollen diagram documents the changes around Megene Chitane over the last century, particularly in the relative amounts of cultivation and woodland and scrub in the catchment. In particular the extent of cultivation has increased during the last two decades, but the total amount of palynological change (Table 1) has been low.

Garaet El Ichkeul (Tunisia) 37º02'N, 9º48'E

Garaet El Ichkeul is a large coastal lake with seasonal high salinity (Stevenson & Battarbee, 1991). Five main rivers supplied the lake with freshwater from the Mogods mountains and the agricultural Mateur depression to the south in winter, but they were all barraged during the 1980s and 1990s (Ramdani et al., 2001a). The Tinja river connects the lake with Lac de Bizerte, and thence with the Mediterranean. The lake is surrounded by marshes and was an important overwintering site for waterfowl. It has RAMSAR status and was made a National Park in 1977. A limestone mountain, Djebel Ichkeul, rises to the south of the lake (Ramdani et al., 2001a).

Palaeoecological investigations by Stevenson et al. (1993) showed that *Pinus* and *Quercus* woodlands have been intensively exploited over many centuries, and were widely replaced with a *Pistacia*-dominated shrub community by ca. 800 yr BP.

In the pollen diagram (Figure 5) tree and shrub pollen average ca. 30% total pollen. In zone 1 *Pistacia*, Ericaceae-type, *Phillyrea*, *Quercus*, *Zizyphus*, *Pinus*, *Olea*, and Thymeleaceae (possibly

Daphne) suggest the occurrence of *Pistacia lentiscus*-dominated scrub communities, probably on the Djebel Ichkeul and the Mogods. High Gramineae percentages are probably from *Phragmites australis* growing around the lake together with *Scirpus maritimus*-type and *Typha domingensis*-type. At about 60 cm depth (zone 2a) pollen of *Pistacia* and some other shrubs declined Pollen of cultivated taxa (Cerealia-type, *Olea*) and herbs associated with grazing and agriculture (e.g., Compositae (Cichorioideae), *Plantago coronopus*type, and *Rumex crispus*-type) increased, suggesting some clearance of the scrub and increased agricultural activity. A similar change in pollen assemblages found by Stevenson and Battarbee (1991) was dated to about 1890 AD, when the Bizerte ship canal was constructed. This concurs with the dating of the present core by Appleby et al. (2001). Gramineae pollen also decreased slightly from about this time and reflects the recorded drainage of some of the marshes and their cultivation. *Eucalyptus* pollen occurred, and *Pinus* and *Olea* pollen increased in zone 2b (ca. 1945). These trees are recorded as having been planted in the 1930s (Ramdani et al., 2001a).

The great reduction in *Phragmites/Scirpus* reedmarsh and its replacement by *Sarcocornia* saltmarsh (Birks et al., 2001) during the early 1990s due to successive river barrages and salinization is barely evident in the upper 8 cm, with only a slight rise in Chenopodiaceae/ Amaranthaceae percentages and concomitant decrease in Gramineae. Appleby et al. (2001) and Birks et al. (2001) report that, after the decline of the aquatic weed beds, the upper loose sediment is mixed by wind turbulence and the record is therefore blurred. This disturbance and the increased input of silt from the canalised rivers could account for the substantial rise in indeterminable pollen that had been damaged by reworking. Besides the dramatic changes in wetland vegetation however, the pollen record indicates little overall change in terrestrial vegetation, as shown by the low total inertia and compositional turnover (Table 1).

Lac de Korba (Tunisia) 36º46’N, 11º00’E

Lac de Korba is a narrow lagoon separated from the Mediterranean by vegetated sand dunes through which seawater can enter at high tide. The river Lobna used to flow into the north end of the lagoon during winter but it has been dammed and that section of the lagoon is now dry. The town of Korba lies at the south end of the lake and there is intensive agriculture to the west (Ramdani et al., 2001a).

The pollen diagram (Figure 6) shows very high percentages of Chenopodiaceae/ Amaranthaceae at the base (zone 1), suggesting that saltmarsh was extensive (possibly the late eighteenth/early nineteenth century). Nineteenth century records show that the lagoon had a much greater connection to the sea. In zone 2, increased Cyperaceae (*Cyperus*-type and *Scirpus maritimus*-type) and decreased Chenopodiaceae/Amaranthaceae pollen percentages reflect a change in the saltmarsh vegetation. Pollen of crops and weeds increased around 20 cm. These levels may date from the end of the nineteenth century when the town of Korba expanded and more land was cultivated. The tree and shrub pollen percentages throughout the diagram reflect the regional occurrence of woodland and shrub communities (*Quercus*, *Pinus*, *Olea*, *Phillyrea*, Ericaceae, Cupressaceae, *Pistacia*). The low local pollen production and very open landscape allowed these anemophilous pollen types to attain relatively high percentages of the total pollen sum.

Over the last 100 years a decrease in Gramineae and concomitant increase in Cupressaceae and *Phillyrea* pollen may suggest conversion of grassland to scrub, possibly as a result of decreased grazing. Increased Chenopodiaceae/Amaranthaceae pollen values at the top of Figure 6 may be correlated with lowering of the fresh-water table and the damming of the river Lobna in 1986 which resulted in saltmarsh expansion and hypersalinity (Kraïem & Ben Hamza, 2000). Overall, the changes in terrestrial pollen are not large, and the medium-high compositional change (Table 1) reflects mainly local vegetational changes.

Egypt

All three Egyptian lakes are large lagoons in the Nile Delta and thus potentially have an immense catchment and pollen source area from Equatorial Africa and the Ethiopian highlands. It was difficult to date the sediments radiometrically and the chronology has been supplemented by biostratigraphic correlation and historical records (Appleby et al., 2001).

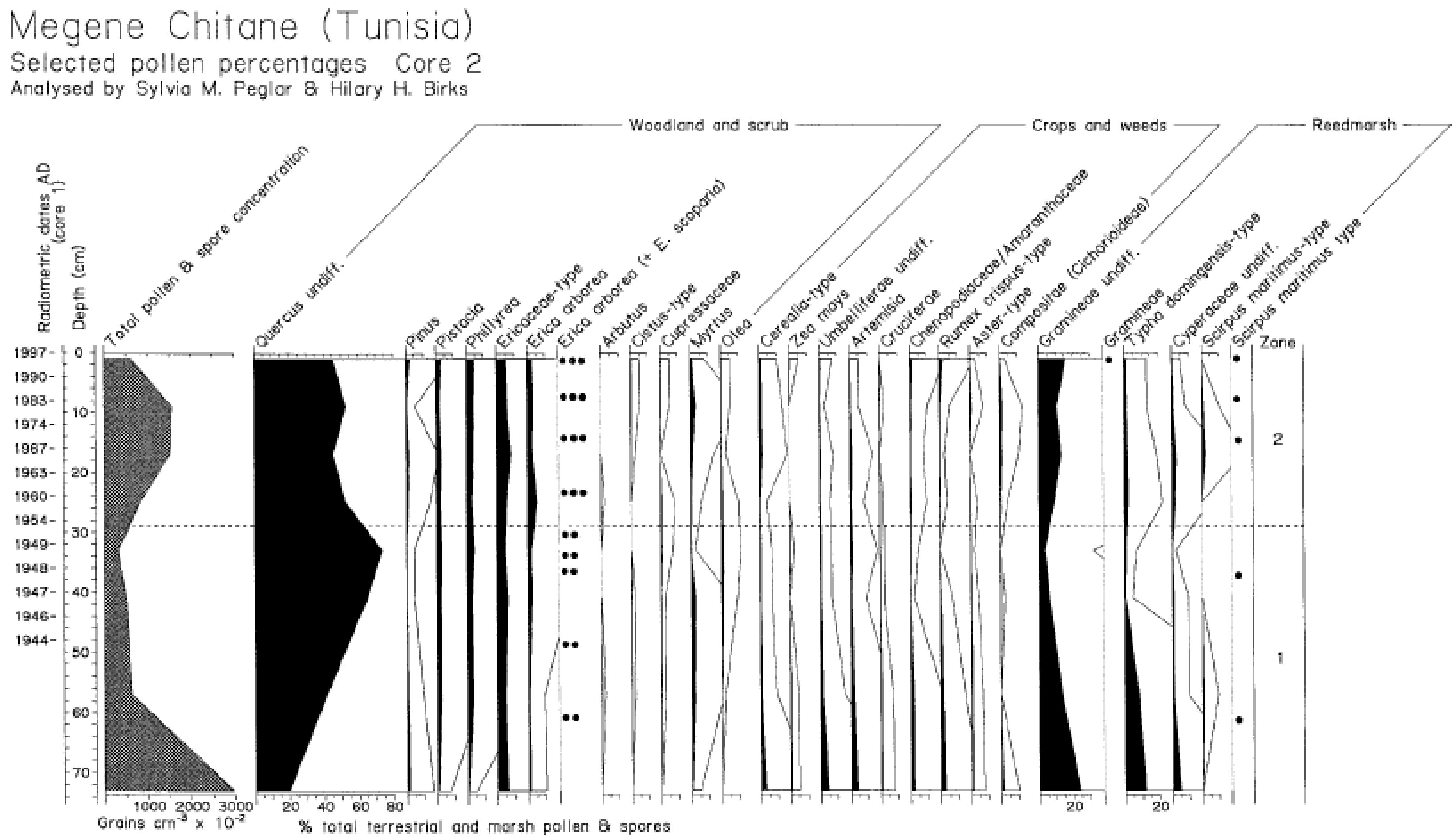

Figure 4. Percentage pollen diagram of selected terrestrial and marsh taxa in core 2 from Megene Chitane, Tunisia. Total pollen concentrations are also shown, and plant macrofossil records from the same core are indicated by dots. Radiometric ages are transferred from measurements on core 1 (Appleby et al., 2001).

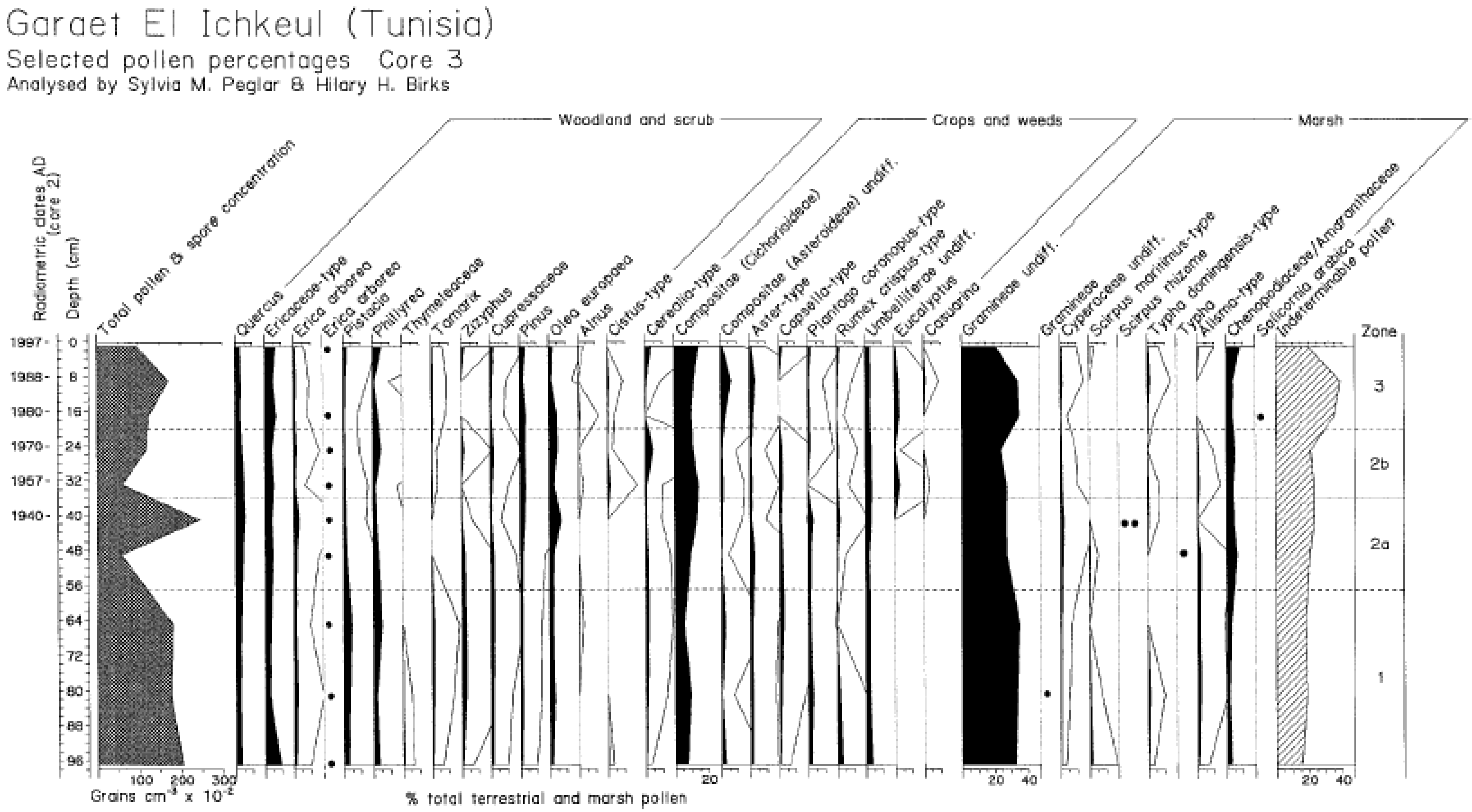

Figure 5. Percentage pollen diagram of selected terrestrial and marsh taxa in core 3 from Garaet El Ichkeul, Tunisia. Total pollen concentrations are also shown, and plant macrofossil records from the same core are indicated by dots. Radiometric ages are transferred from measurements on core 2 (Appleby et al., 2001).

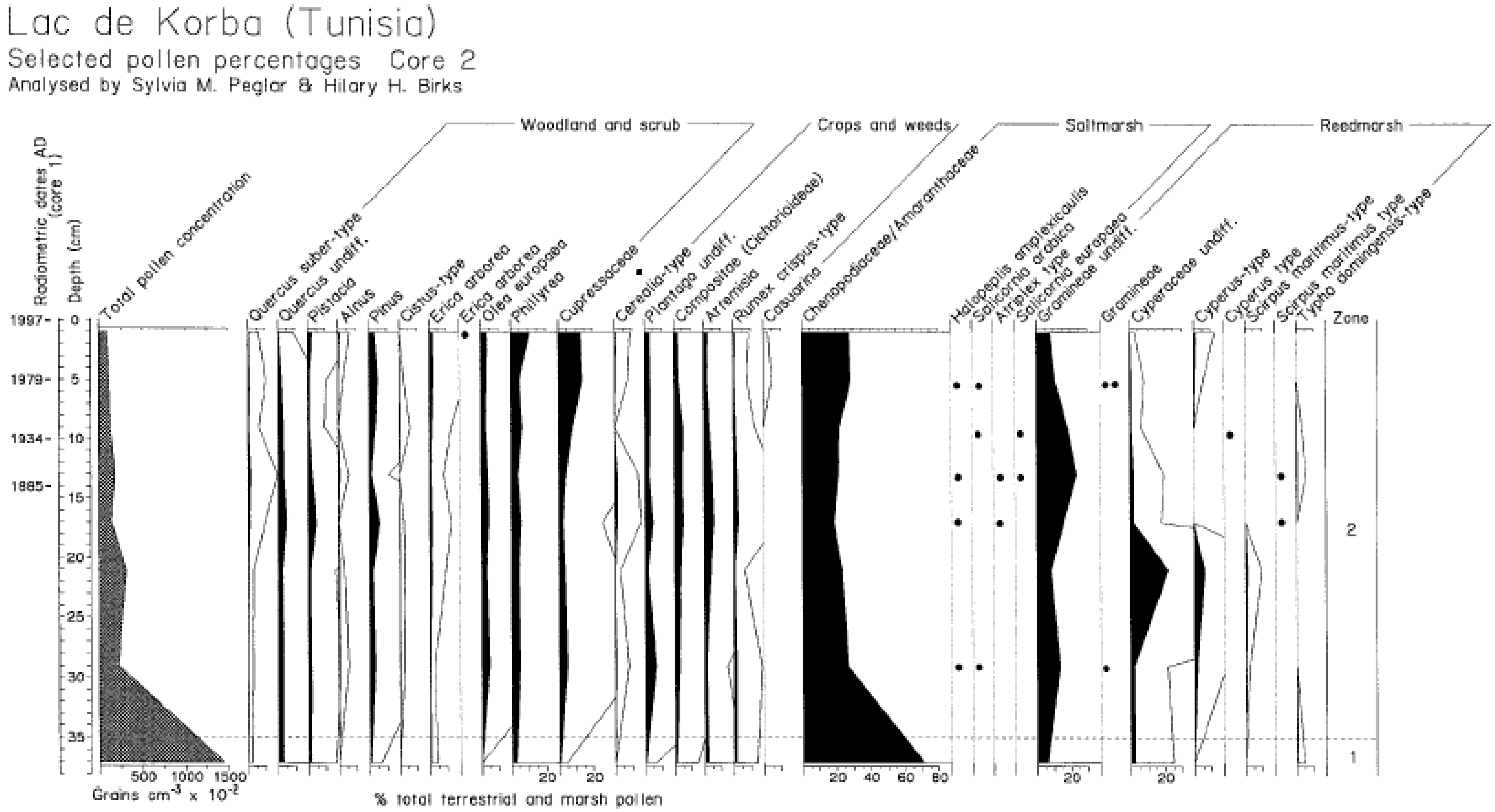

Figure 6. Percentage pollen diagram of selected terrestrial and marsh taxa in core 2 from Lac de Korba, Tunisia. Total pollen concentrations are also shown, and plant macrofossil records from the same core are indicated by dots. Radiometric ages are transferred from measurements on core 1 (Appleby et al., 2001).

Edku Lake 31º15’N, 30º15’E

Zone 1 (Figure 7) is dominated by Chenopodiaceae/Amaranthaceae and Gramineae (probably *Phragmites*-type) pollen and other taxa of saltmarsh and reedmarsh. At about 45 cm (zone 3, early twentieth century) saltmarsh declined (decrease in Chenopodiaceae/Amaranthaceae). An increase in Gramineae and in cultivated plants and their associated weeds, including Cerealia-type, *Vitis*, Leguminosae, *Olea europaea*, *Phoenix dactylifera*-type, *Pinus*, Compositae, *Heliotropium*-type, *Plantago*, *Morus alba*-type, and *Rumex crispus*-type, marks the increase of intensive agriculture around the lake after ca. 1920 following year-round irrigation made possible by the progressive improvement of the Nile barrages (Waterbury, 1979). *Casuarina* and *Eucalyptus* were increasingly planted after ca. 1920 (Täckholm & Drar, 1941–1969; Mehringer et al., 1979) to provide shelter for crops, firewood, and dune stabilisation, and their pollen is first recorded at 35 cm (ca. 1930). *Typha domingensis*type pollen also started to increase ca. 1920 marking an increase in *Typha domingensis* in the *Phragmites*dominated reedmarsh. In zone 4 there is a further increase in *Typha* probably as a result of the expansion of reed-marsh towards the coring site (Birks et al., 2001).

At Edku and Burullus (Figure 8) *Podocarpus* pollen is found together with that of various tree species not native to the Egyptian flora. These are probably transported from long distances by Nile water or by the air. *Podocarpus* spp. are planted in gardens in Alexandria (Täckholm& Drar, 1941–1969) presumably since ca. the 1850s, when *Casuarina* spp. were also first introduced. The absence of *Podocarpus* pollen in the Manzala Lake record (Figure 9) may be due to its considerable distance from Alexandria.

Burullus Lake, 31º21–31º35’N, 30º30–31º10’E

The pollen diagram (Figure 8) is similar to that from Edku (Figure 7), with Gramineae (*Phragmites*?) and Chenopodiaceae/Amaranthaceae dominating in zones 1 and 2. In zone 3 (ca. 1945) Gramineae declined and was joined by *Typha*. Chenopodiaceae/Amaranthaceae pollen remained high until *Typha* expanded (zone 3, ca. 1950s; Appleby et al., 2001). The decrease in saltmarsh later at this site than at Edku may be explained by the higher salinity maintained at Burullus Lake through its more effective connection to the sea, so that the addition of freshwater had less impact on the vegetation (see Birks et al., 2001 for the detailed palaeolimnological history).

Signs of cultivation increased above 30 cm (early twentieth century). *Casuarina* and *Eucalyptus* were first recorded at 8 cm (ca. 1960). This late date and the smaller representation of taxa associated with cultivation may reflect the distance of the core site from the fertile south shore and the relatively little cultivation on the desert-like north shore adjacent to the core site.

Manzala Lake 31º00–31º30’N, 31º45–32º15’E

The pollen diagram (Figure 9) follows a similar pattern to Edku and Burullus. Gramineae is dominant at the base, then decreased as Chenopodiaceae/Amaranthaceae increased, suggesting a more saline phase in zone 2 with extended saltmarsh, equivalent to zone 1 at Edku and Burullus. *Typha domingensis*- type expanded ca. 50 years ago in zone 3. The lake and marsh development is discussed by Birks et al. (2001). Expansion of agricultural indicators occurred at about the same time as the expansion of the saltmarsh during zone 2, somewhat earlier than at Edku and Burullus.

The pollen records from all three Egyptian lakes are similar (Figures 7–9) and show a high total variance and relatively high compositional change (Table 1). This reflects large changes in marsh vegetation and marked terrestrial changes resulting from cultivation.

The decline in saltmarsh, particularly obvious at Edku and Manzala, was probably connected with the building of Nile barrages from the late nineteenth century onwards (Waterbury, 1979) and it is associated with marked increases in taxa associated with cultivation. The Aswan High Dam was closed in 1964 and resulted in increased freshwater influence in the lakes (Waterbury, 1979; Appleby et al., 2001; Birks et al., 2001). Although perennial irrigation was established throughout the Nile Delta as a result, the pollen diagrams show little evidence of increased cultivation intensity at this time, mainly because the crop plants, e.g., cotton, produce small amounts of poorly dispersed pollen.

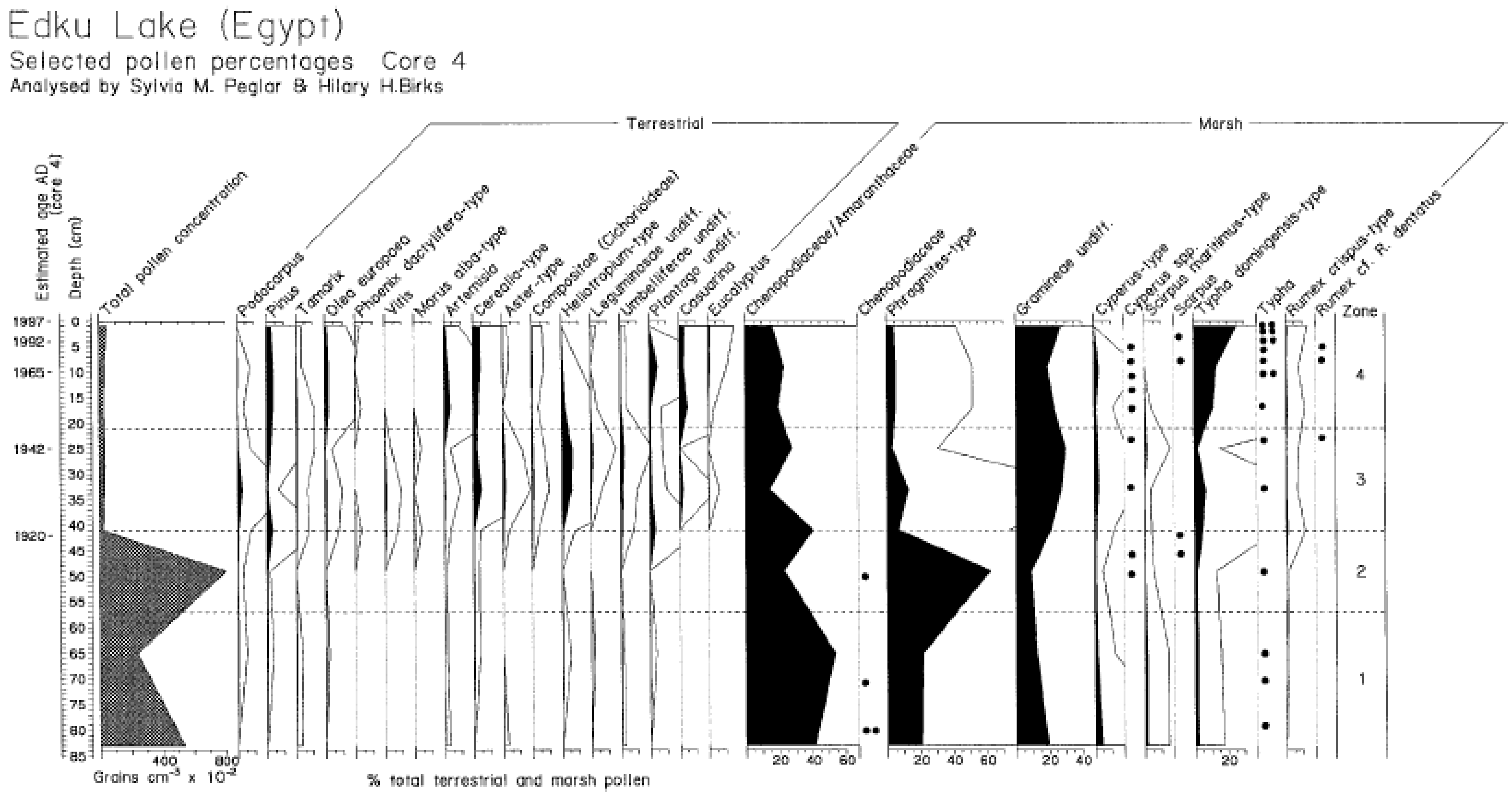

Figure 7. Percentage pollen diagram of selected terrestrial and marsh taxa in core 4 from Edku Lake, Egypt. Total pollen concentrations are also shown, and plant macrofossil records from the same core are indicated by dots. Ages are estimated from the timescale constructed by Appleby et al. (2001).

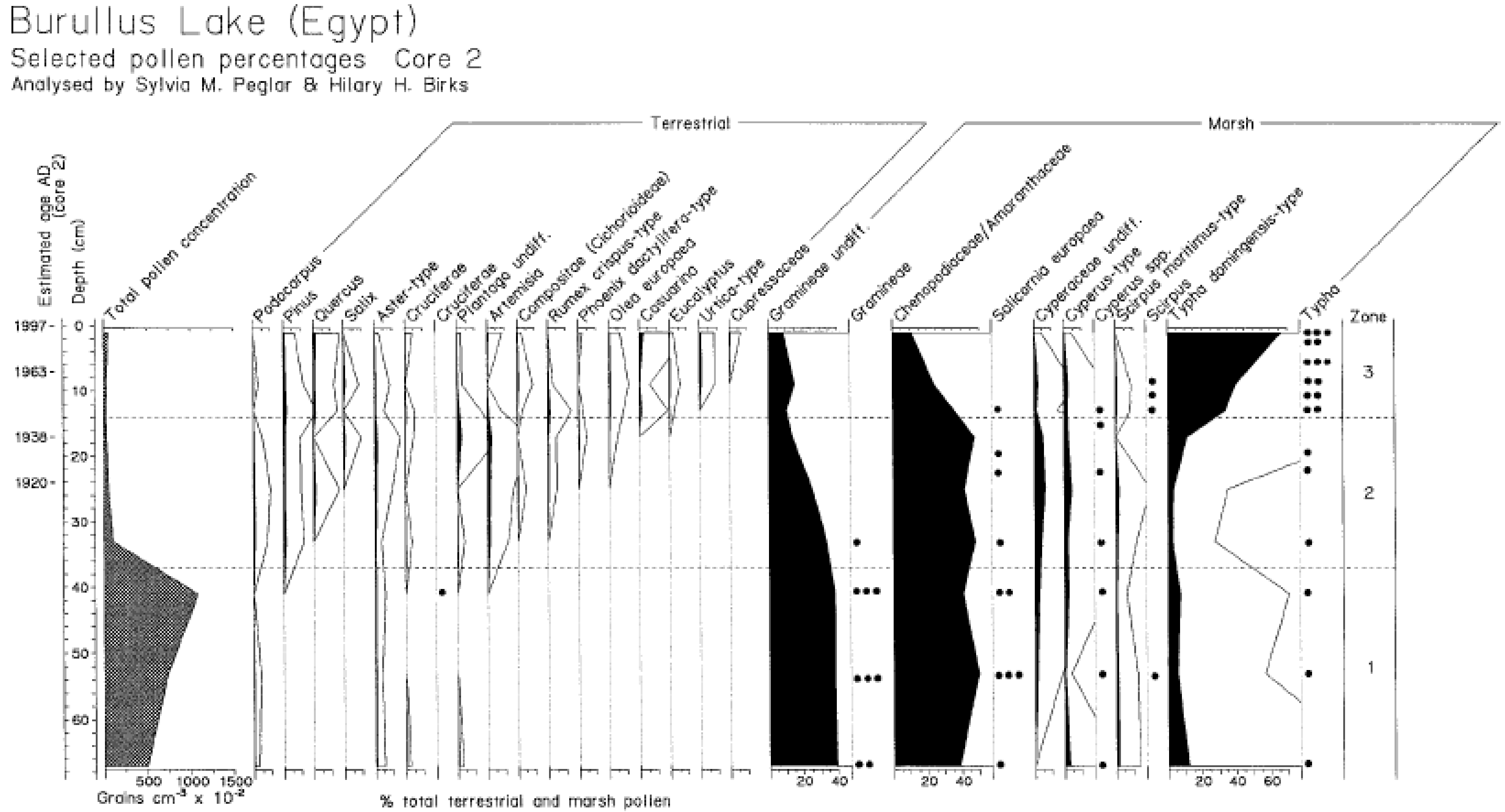

Figure 8. Percentage pollen diagram of selected terrestrial and marsh taxa in core 2 from Burullus Lake, Egypt. Total pollen concentrations are also shown, and plant macrofossil records from the same core are indicated by dots. Ages are estimated from the timescale constructed by Appleby et al. (2001).

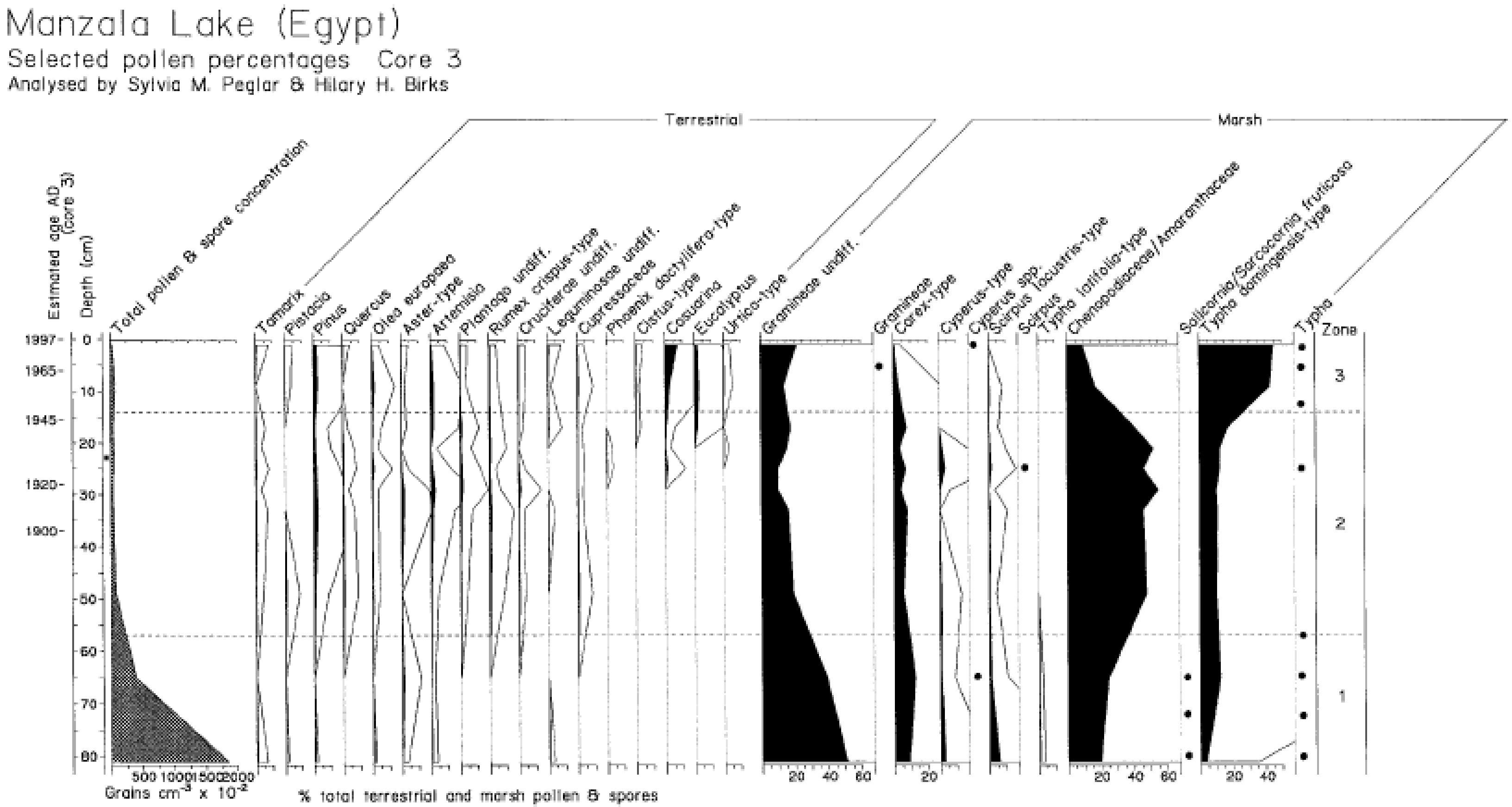

Figure 9. Percentage pollen diagram of selected terrestrial and marsh taxa in core 3 from Manzala Lake, Egypt. Total pollen concentrations are also shown, and plant macrofossil records from the same core are indicated by dots. Ages are estimated from the timescale constructed by Appleby et al. (2001).

The increased planting of fruit trees (e.g., *Phoenix* – date palm, *Olea* – olive) since ca. 1940 (Mehringer et al., 1979) is reflected in increased values of their pollen in all three diagrams. The occasional absence or late arrival of their pollen in the record could be explained by their non-local presence or their non-representation due to high local pollen production. The appearance and expansion of these pollen types, together with the introduced taxa *Casuarina* and *Eucalyptus* provide an approximate timescale for the sediments, and have been used in conjunction with other biostratigraphical evidence and radiometric measurements to produce a chronology for each site (Appleby et al., 2001).

Conclusions

The pollen analyses have shown that, although all these North African sites have been subjected to human impact over the past 100–150 years, the vegetation around some of them has remained fairly stable over this time whereas others show a large degree of change (Table 1).

Of the Moroccan sites, Merja Sidi Bou Rhaba shows a moderate amount of change, Merja Zerga shows little change over the past century (Table 1), while the third, Merja Bokka, has experienced continued severe water withdrawal, culminating in its drying out and subsequent cultivation in 1998.

In Tunisia neither Garaet El Ichkeul nor Lac de Korba have seen extensive upland change (Table 1), but Megene Chitane has experienced some change, particularly over the last twenty years or so with increasing cultivation in its small catchment. Although the changes in the pollen diagrams are relatively small, the quality of the change has been important in the small or large effect(s) on the lake hydrology and ecosystem. Changes in the catchment affect the lake, but are not necessarily represented by pollen changes, especially in large pollen catchments.

The Egyptian Delta lakes have seen tremendous changes over the past 100 years (Table 1), as populations around them have rapidly increased. Although the area has experienced human impact for several thousand years, it is only in the last 100 years that this has rapidly intensified (Butzer, 1976).Most of the Delta is now cultivated and urbanised, and increased freshwater influence has encouraged reedswamp expansion in many parts of the lakes.

Perhaps most important to the lakes and their catchments are the changes during the last 1–2 decades. If things continue as they are, then many irreversible changes will take place, such as at Merja Bokka, where the lake bed has now been cultivated. The remaining wetland sites are important for human society, for birds, and for aquatic biodiversity in maintaining hydrological balance and water supply in the catchments. Although the main priority is for people to be fed, it is shortsighted to destroy the very wetlands that are a necessary part of ecosystem sustainability in these arid climates.

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